# Evolution and Complexity: How the Universe created wealth (diversity) and how humans are destroying it. Is there a future for mankind?

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# The underlying physics

- Energy is the building block of the universe
- Energy is conserved: neither created nor destroyed (the First Law of thermodynamics).
- But not all energy can do work (lift, push, accelerate, etc.) The useful part is called exergy. The other part is called anergy.
- Exergy is not conserved. Doing work destroys exergy and increases entropy.
- The second law of thermodynamics says that Energy always flows from hot to cold, from order to disorder.

# What is ENTROPY ?

- It is a state, not a substance.
- It increases every time there is any action (or any flow of exergy)
- It is the “arrow of time”
- It is (roughly speaking) a measure of disorder.
- It is a ratio of probabilities: toward more probable v. toward  less probable

# The universe as a heat engine

The expansion of the universe is like the expansion stroke of a heat engine: it converts heat and pressure into kinetic energy. The work being done is not against a piston, but is against the force of gravity acting from the center of mass.

The work that is being done is "symmetry breaking", or creation of gradients or differentiation and/or complexification.

# At first there was perfect symmetry: All possible states were superimposed, no gradients

- Elementary particles were spontaneously "condensed" from "the vacuum", as it cooled. Particle-anti-particle pairs instantaneously recombined and self-destructed.
- Why is the number of anti-particles not equal to the number of particles"?
- But why is the number of protons equal to the number of electrons? (No net charge)
- It's a puzzle.

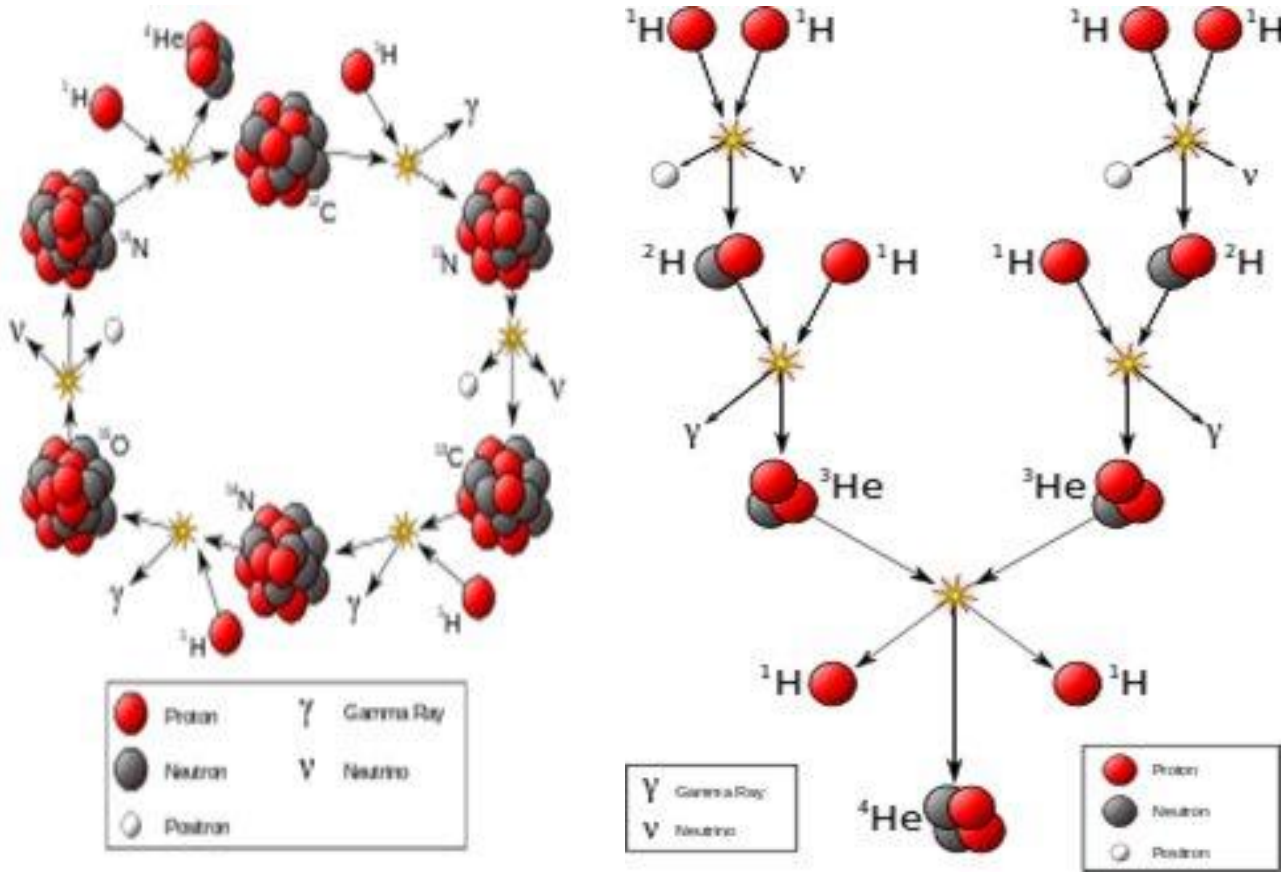
# The first symmetry-breaking transitions

- At the BB all forces/carriers were indistinguishable (perfect symmetry)
- First fermions(that occupy space) were distinguished from "bosons" (that don't). Fermions have half integer "spin", bosons have integer spins.
- Then came electric charge (+, - or 0) and mass (+,- or 0)
- The "strong force" is distinguished from the electro-weak force.
- Fermions split into quarks (that "feel" the strong force) and leptons (that don't feel it).
- Then the "electro-weak" force also split and electromagnetism was distinguished from the "weak" force. Chirality (right/left "handedness")not conserved.

# Later

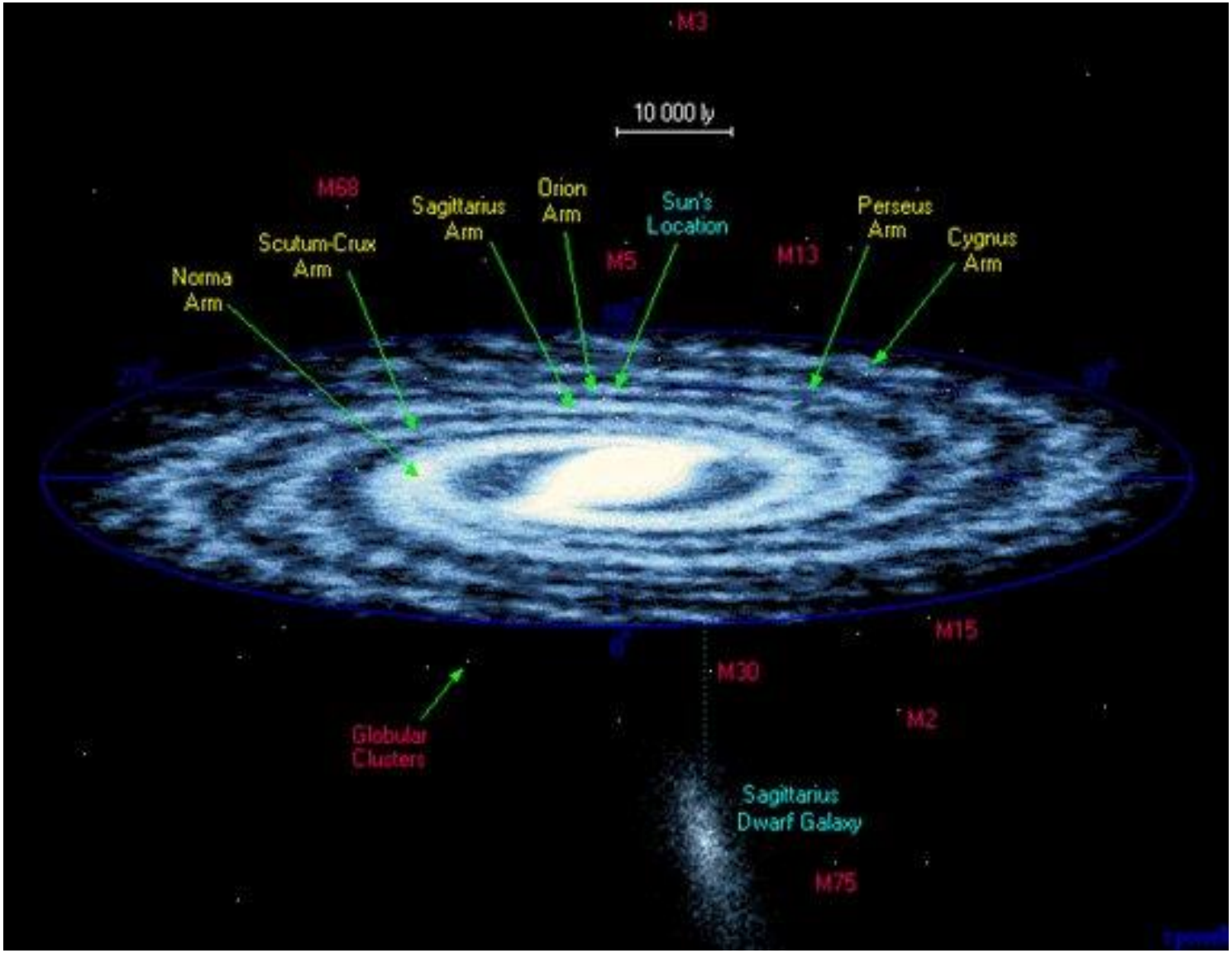
- Quantum fluctuations broke the early symmetry of uniformity, homogeneity and isotropy
- Gravitational force created density variations, resulting in proto stars.
- Gravitational force (pressure) in stars enabled fusion of H, He, up to iron. Fusion made the stars "shine".
- Gravitational collapse of large stars (super-novae) (after exhaustion of H, He) created heavier elements and interstellar dust
- Dust clouds condense to form new planets and stars, such as Earth.

# The carbon-nitrogen cycle and the proton-proton chain for synthesis



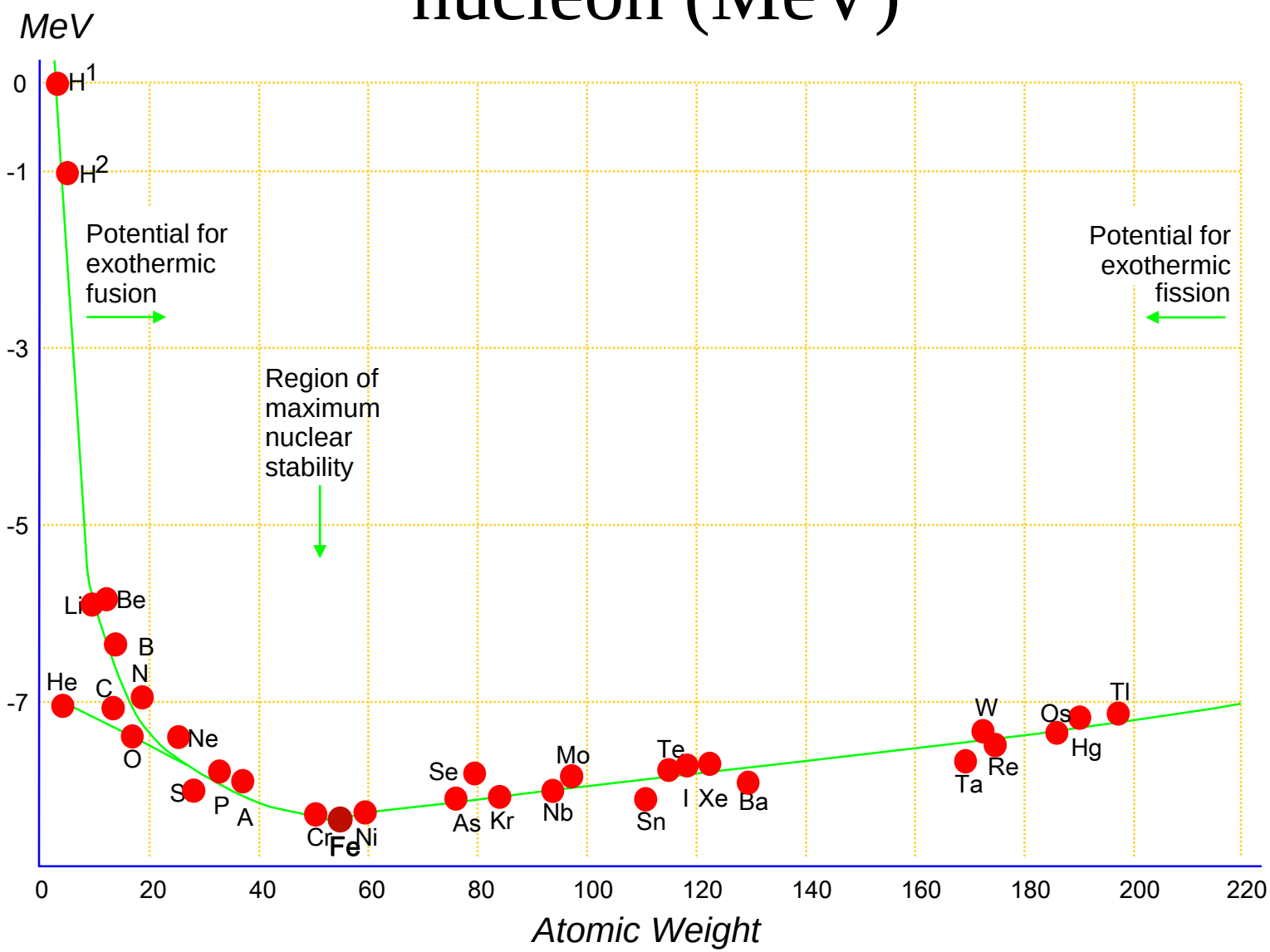

*Source: https://en.wikipedia.org/wiki/CNO_cycle*

# The Milky Way – our Galaxy



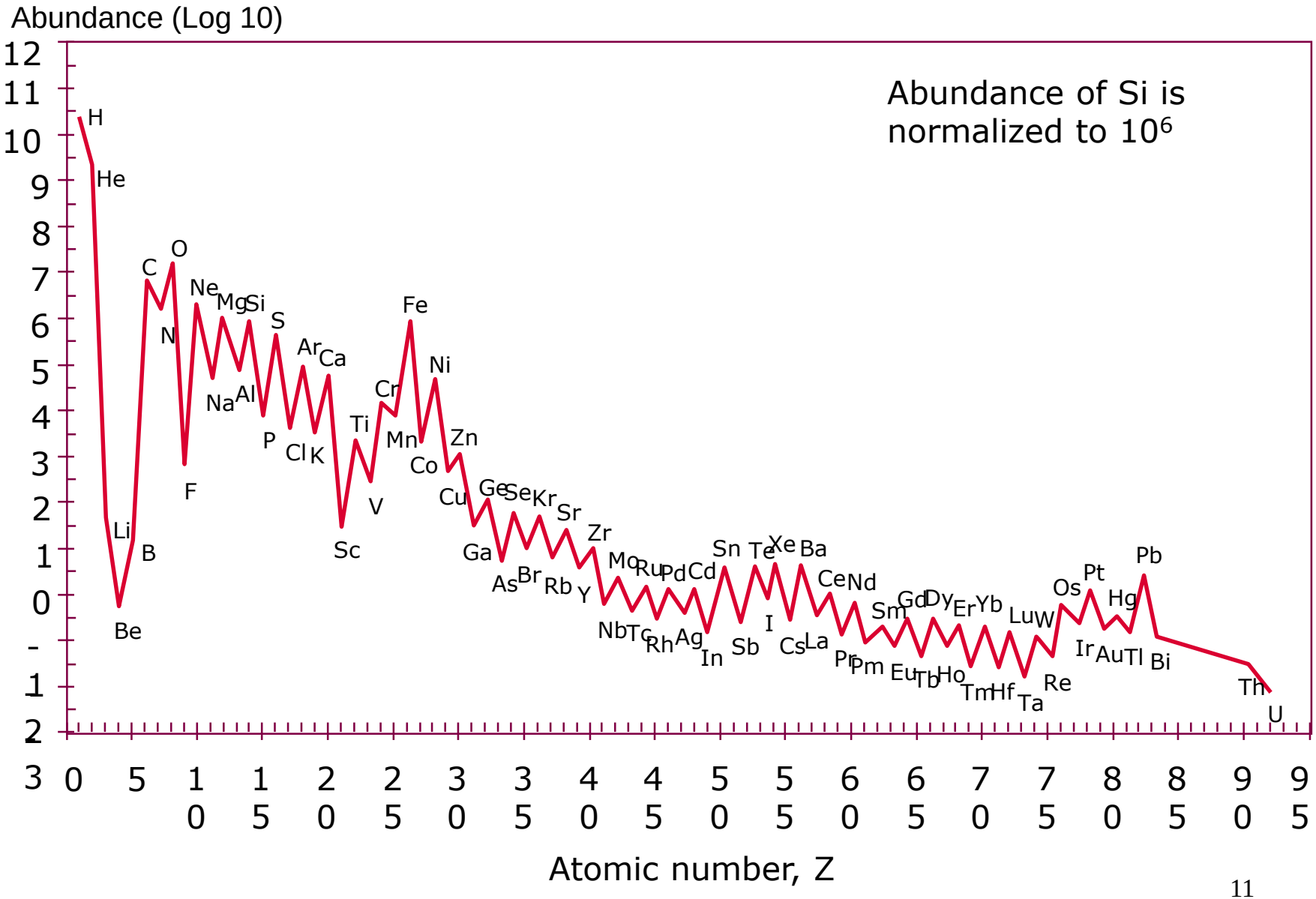

*Source: http://www.atlasoftheuniverse.com/galaxy.html*

# Nuclear binding energy (potential) per nucleon (MeV)




*Source: [adapted from Aston 35,36; Bainbridge 32,33]*

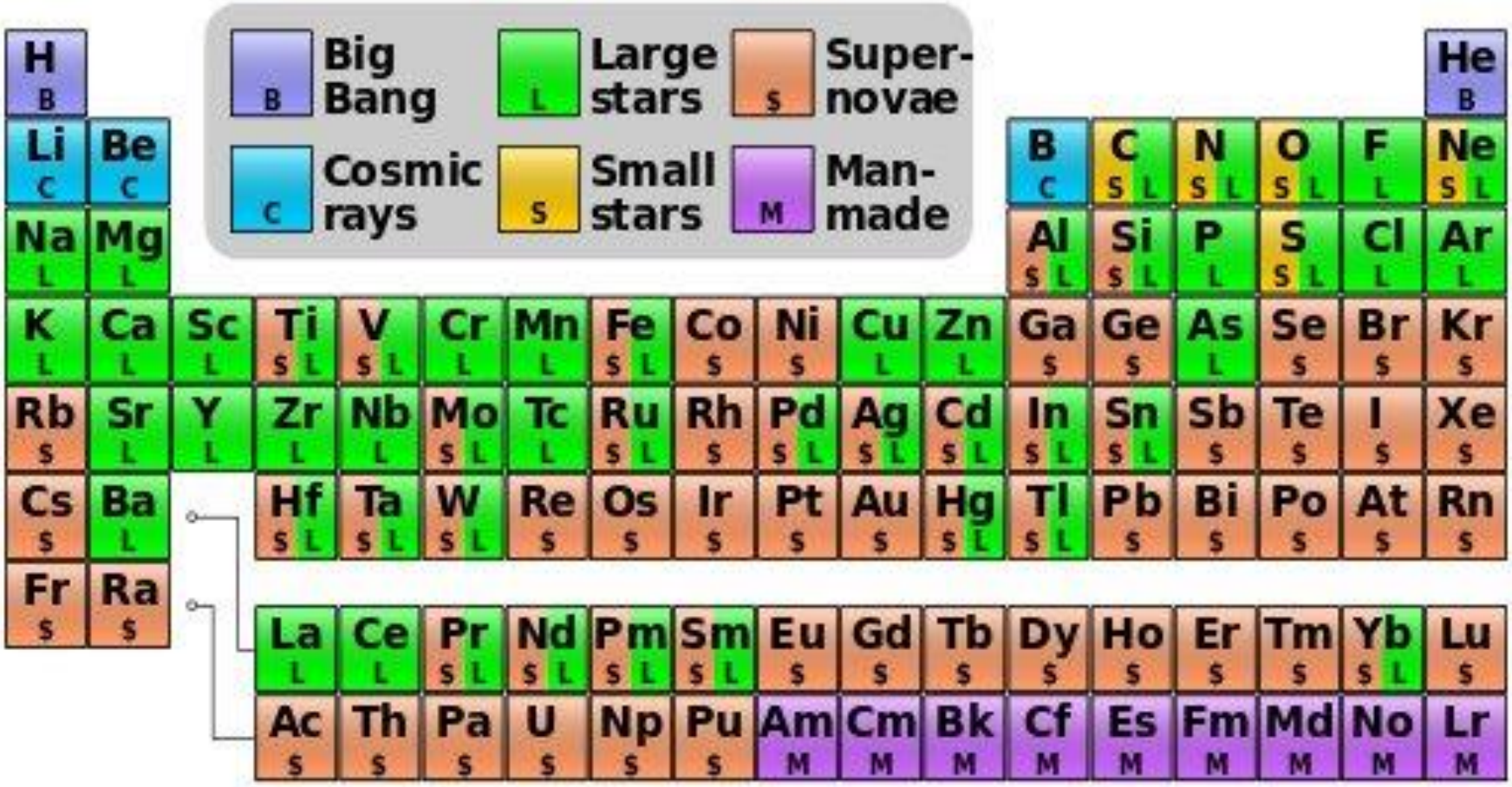
# Elementary abundances






*Source:https://commons.wikimedia.org/wiki/File:SolarSystemAbundances.png#/media/File:SolarSystemAbundances.png)*

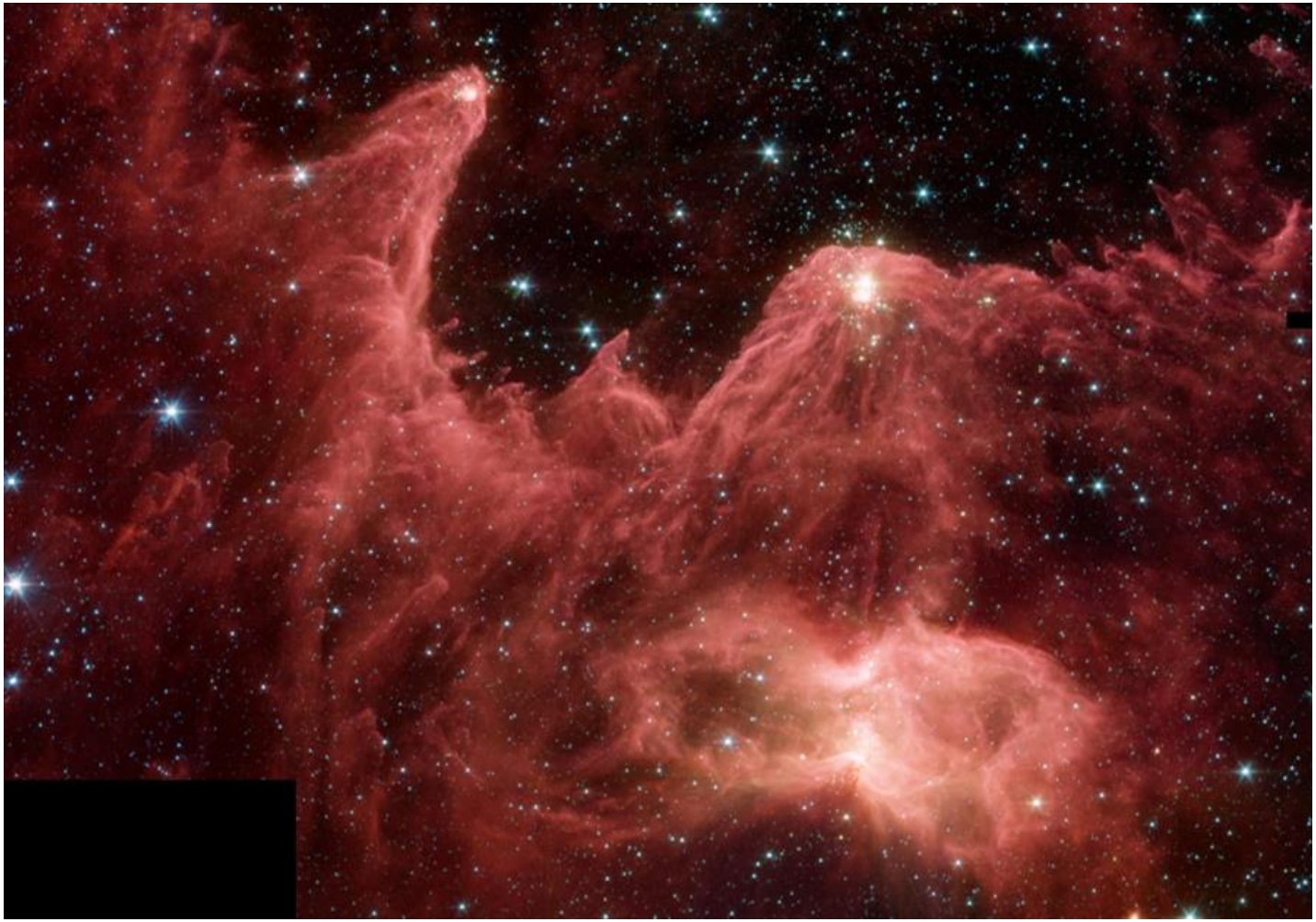
# Periodic Table showing origin of elements – and wealth




*Source: https://en.wikipedia.org/wiki/Stellar_nucleosynthesis*

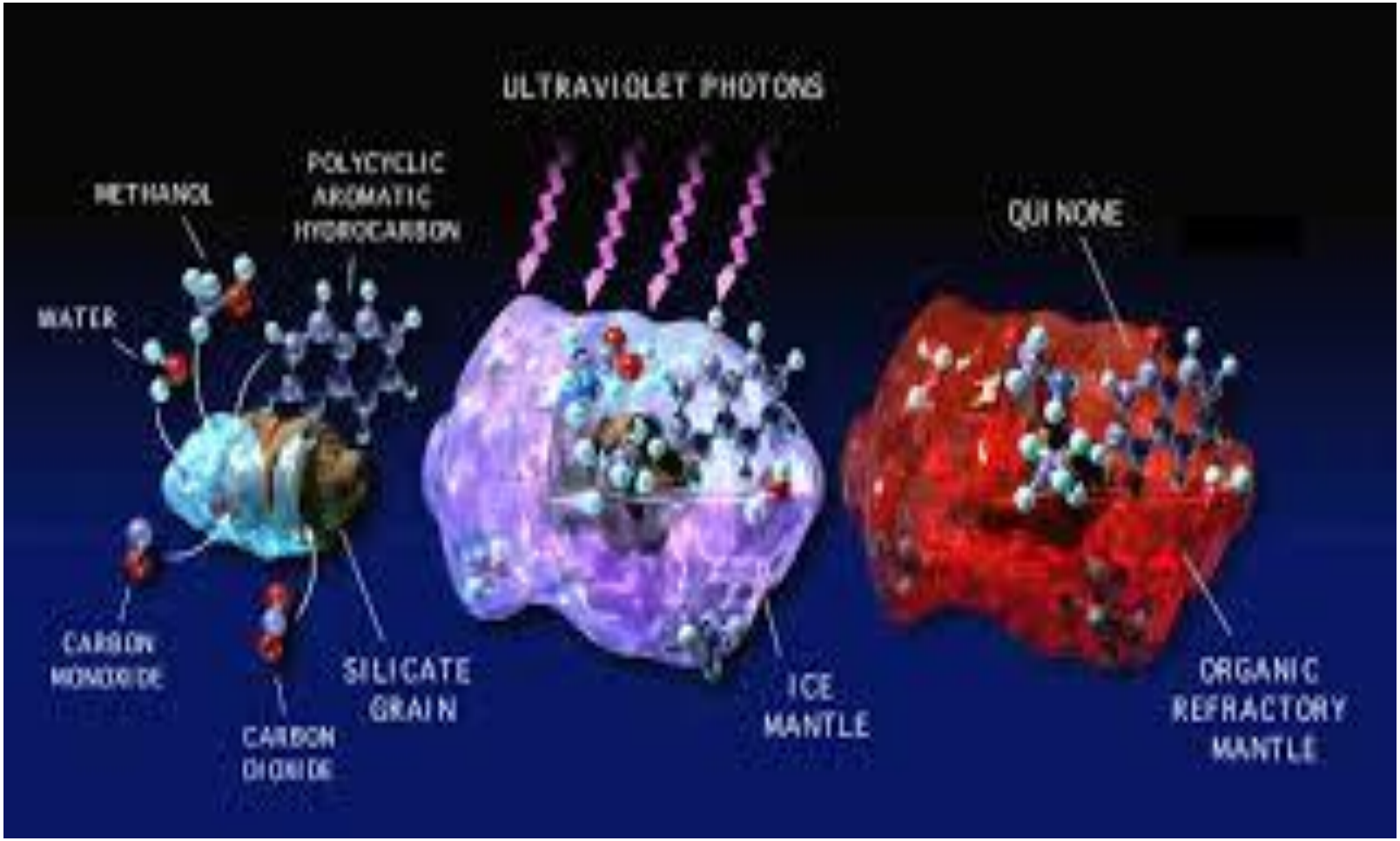
# A gas cloud in Cassiopeia

The red color indicates that organic compounds are present



http://photojournal.jpl.nasa.gov/catalog/PIA03096

# Silica grains in dust clouds where UV-driven chemical reactions can take place

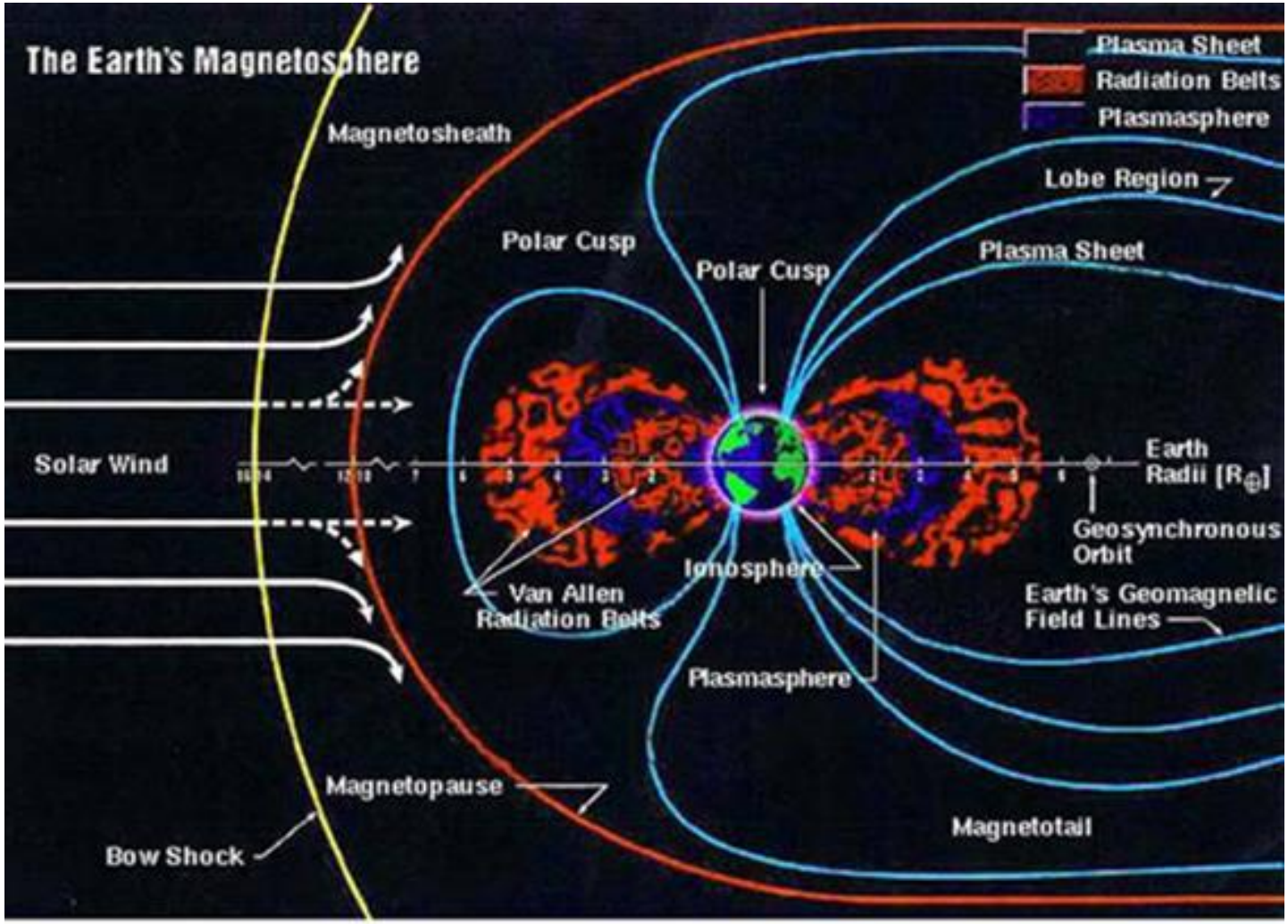



http://www.astrochem.org/sci_img/icegrain.jpg

# The sun and solar system

- Our sun is “middle-aged”: 5 billion years old. It is now 15 deg.C warmer than at the beginning.
- The planets formed in a disk-shaped dust cloud, from density inhomogeneities that became gravitational attractors.
- The Earth was originally two planets that collided. The larger one kept all the heavy elements, including the iron core. The smaller one (which causes tides) is the moon.
- Convection currents in the iron-nickel core generate the magnetic field that protects Earth from cosmic rays and solar wind.

# The Magnetosphere of the Earth




*Source: http://gbailey.staff.shef.ac.uk/researchoverview.html*

# Geology: ore differentiation

- Magmatic
  - Cumulate deposits – fractional crystallization processes can concentrate metals (Cr, Fe, Pt)
  - Pegmatites (holocrystalline rock), mostly quartz, feldspar, mica); late stage crystallization forms other pegmatites (Li, Ce, Be, Sn, and U)
- Hydrothermal
  - Magmatic fluid - directly associated with magma
  - Porphyries - Hot water heated by contact with plutons (intrusive igneous rock crystalizing from magma)
  - Skarn – hot water associated with contact metamorphisms
  - Exhalatives – hot water flowing to surface
  - Epigenetic – hot water from other sources

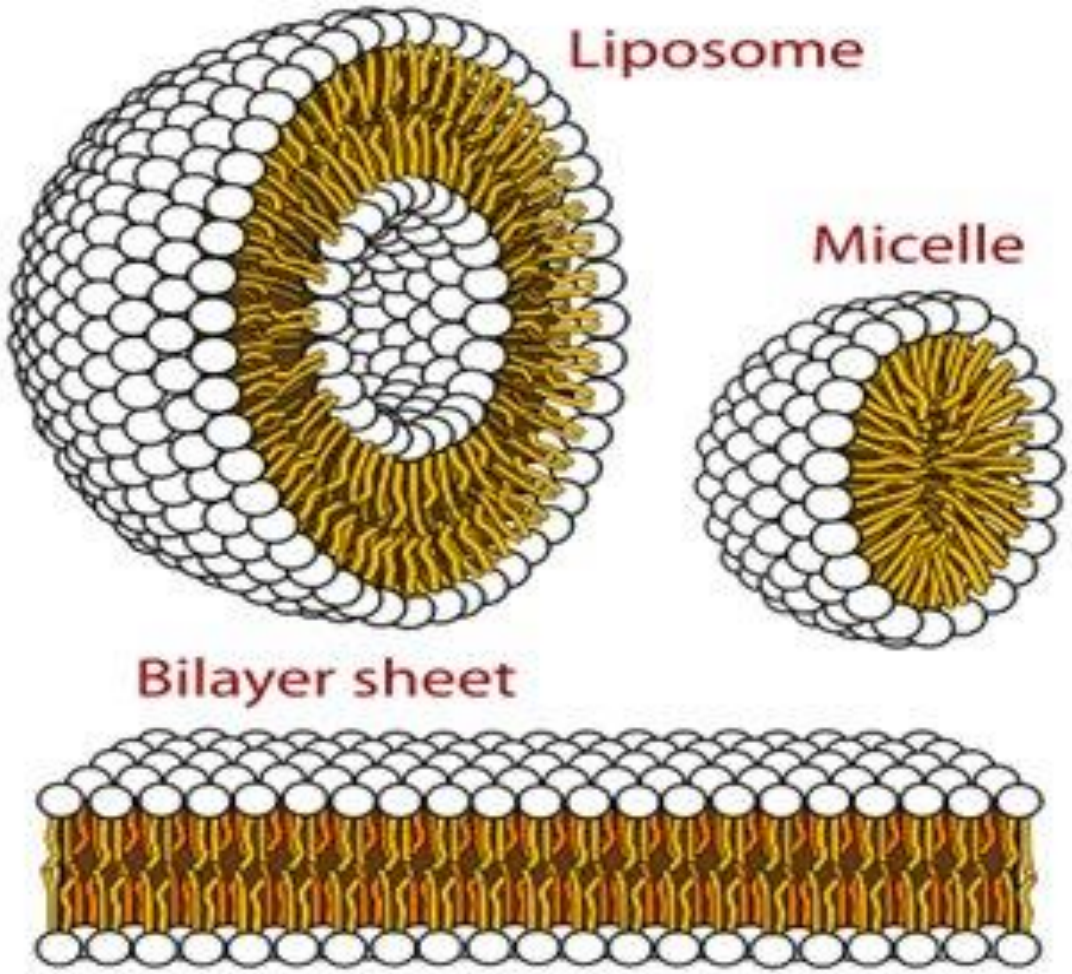
# Bio-chemistry becomes important

- The early atmosphere was "reducing" i.e. methane, ammonia, CO2, N2, but no oxygen (?) and no ozone-layer. (doubts)
- Small molecules formed on silica dust particles in space (protected from UV) in clouds. Some are deposited on Earth by comets or as organic "chondrites" in meteorites.
- Self-reproducing macro-molecules) like RNA emerged. Nobody knows how, but plausible theories exist.

# More symmetry-breaks, greater complexity as life evolved on Earth

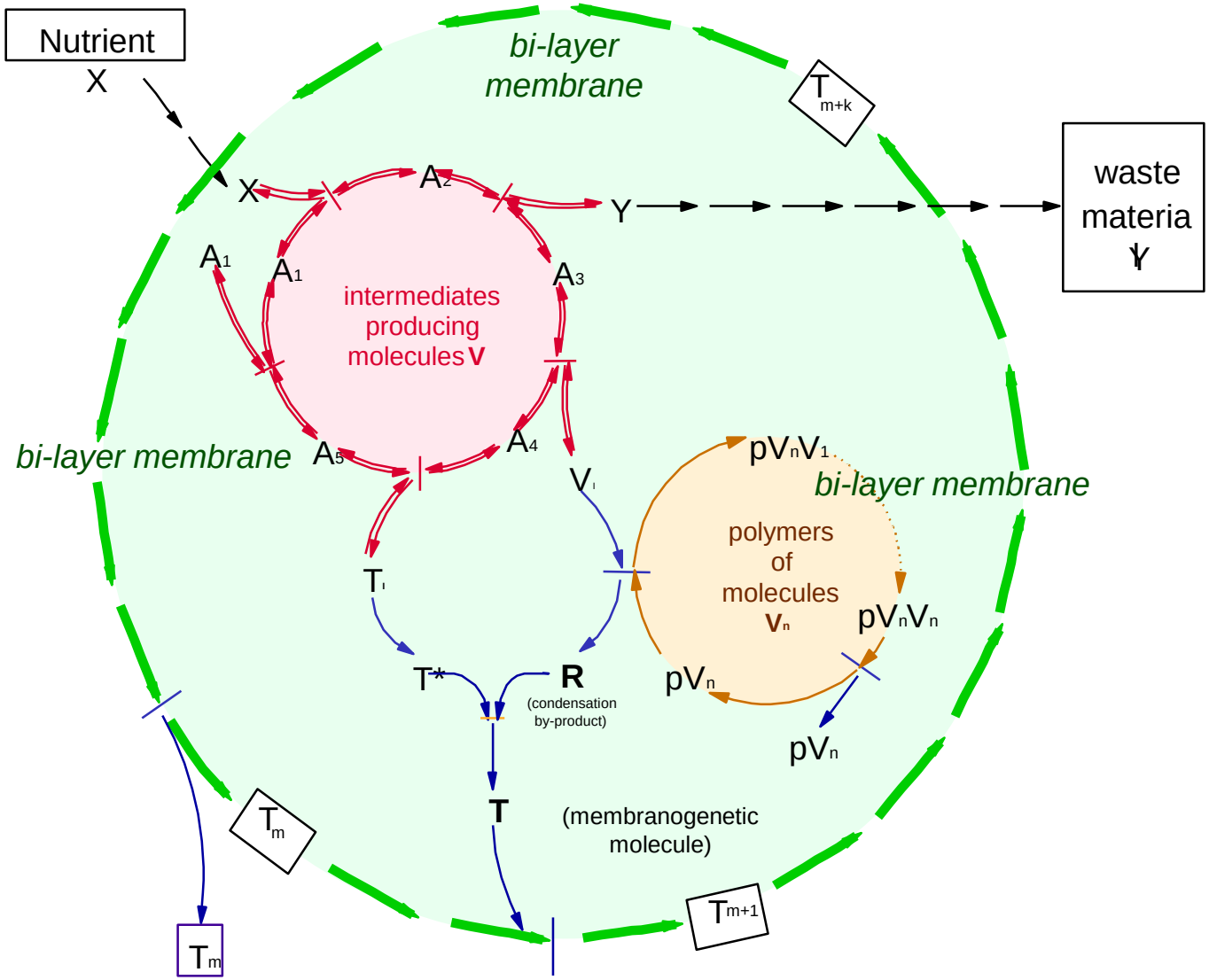
- Atmosphere, oceans (liquid water) on a solid crust result in surfaces where small molecules react to produce larger (more stable) ones
- Stable ions e.g. amino acids, carboxy chains, phosphates, accumulate in aqueous solution
- Membranes (with 2 sides) evolve from phospho-lipids. Distinction between inside and outside.
- Cyclic auto-catalytic synthesis reactions evolve inside membrane bubbles (cells).
- Metabolism based on fermentation of “food”

# Formation of bi-polar lipo-phosphate membranes: The origin of cells




*Source: Wikimedia, Mariana Ruiz*

# Schematic model of the Chemoton: A self-replicating chemical system

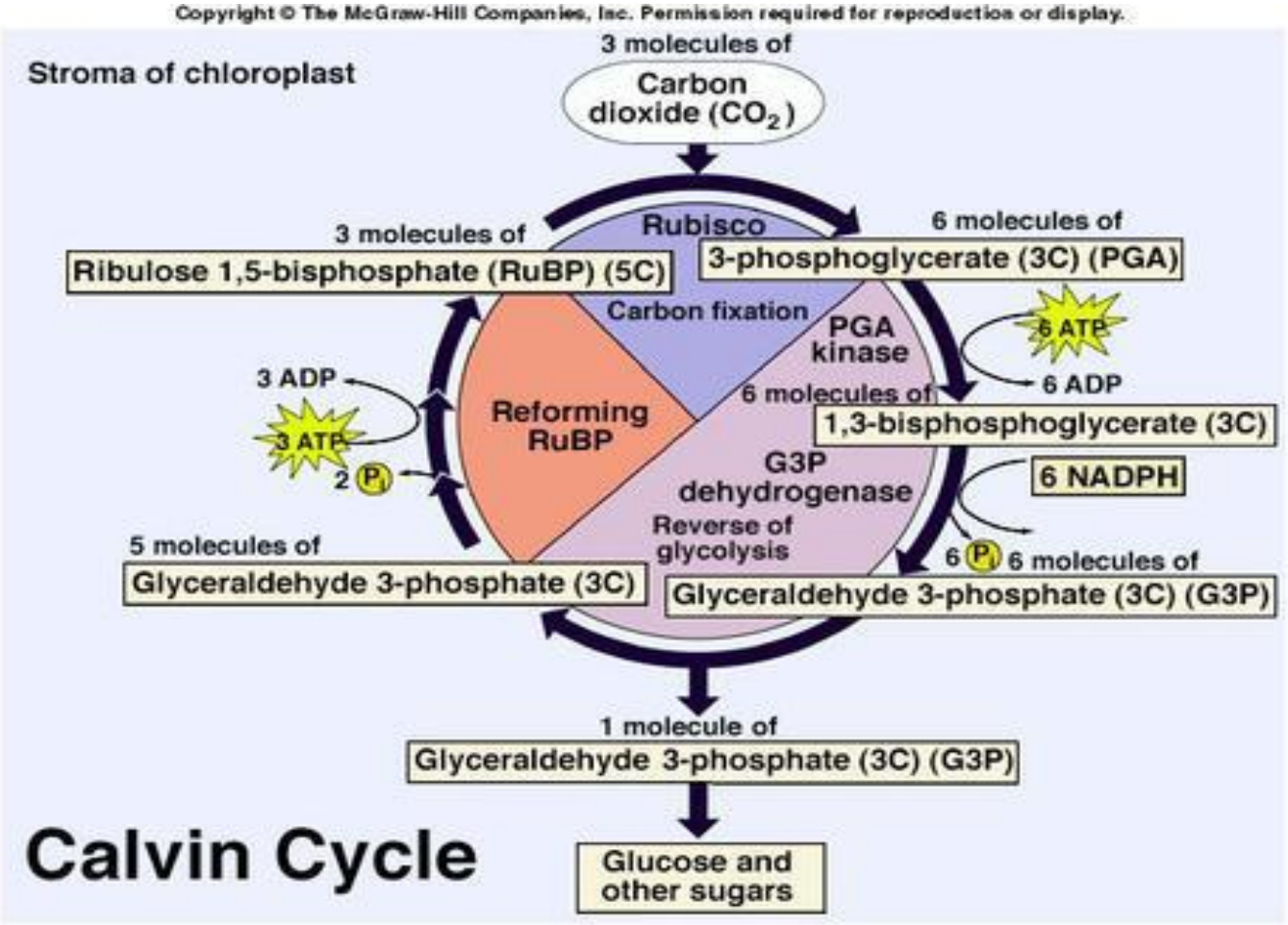



*Source: adapted from (Smith and Szathmary 1995, Figure 2.2 p. 21)*

# Still more symmetry-breaks, more differentiation, more complexity

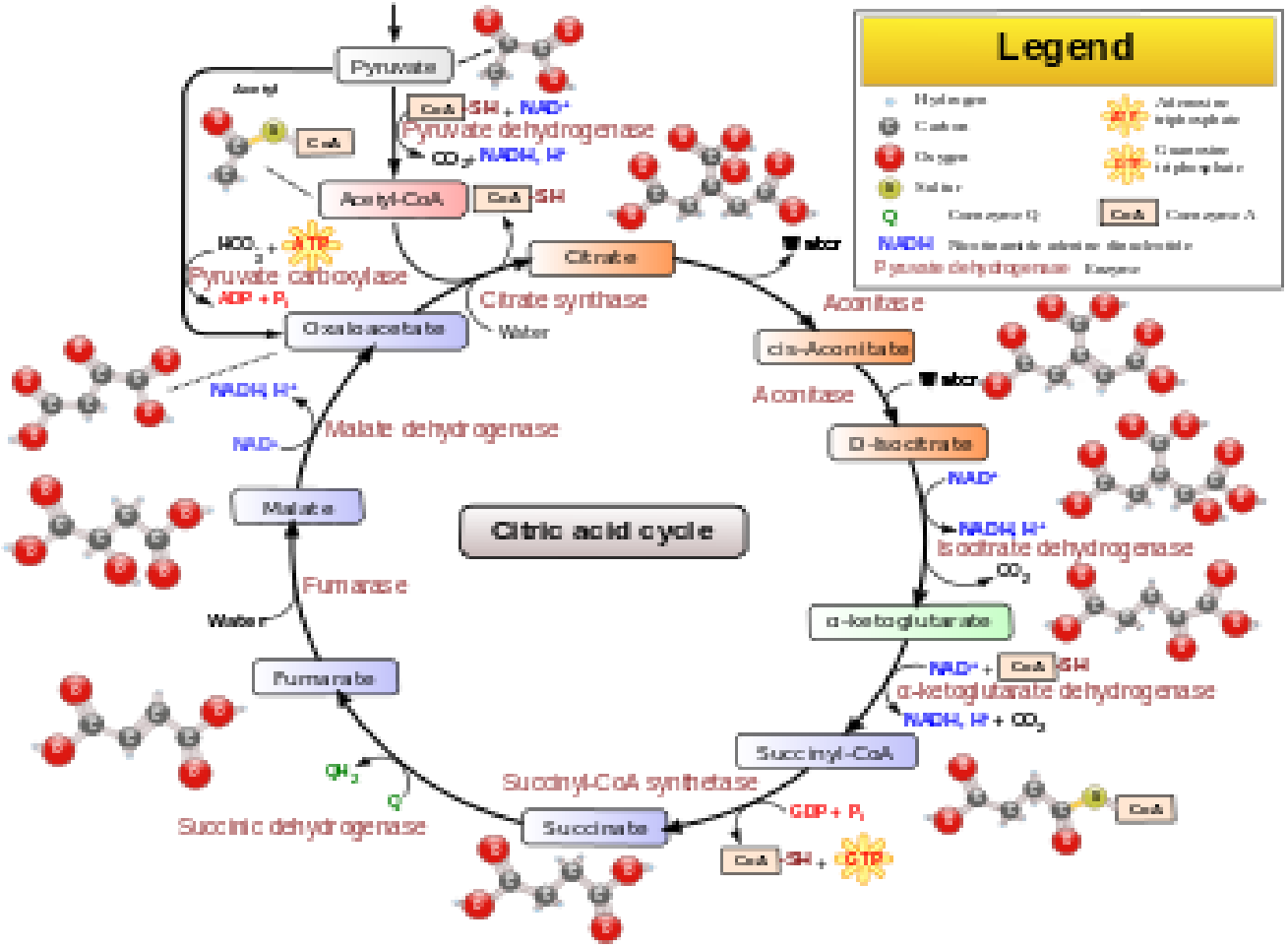
- Prokaryotes specialize in different environments
- Mergers create eukaryotes with internal “organs”
- Photo-synthesizers (plants) differentiate from “grazers”(animals)
- Oxygen respiration permits greater mobility
- Multi-cellular organisms are more efficient. The “food chain” evolves.
- Sexual reproduction
- Skeletons, invasion of land, warm blood, mammals

# The photosynthesis cycle




http://www.mhhe.com/biosci/genbio/enger/student/olc/art_quizzes/genbiomedia/0158.jpg

# The Krebs (citric acid) cycle for oxygen respiration

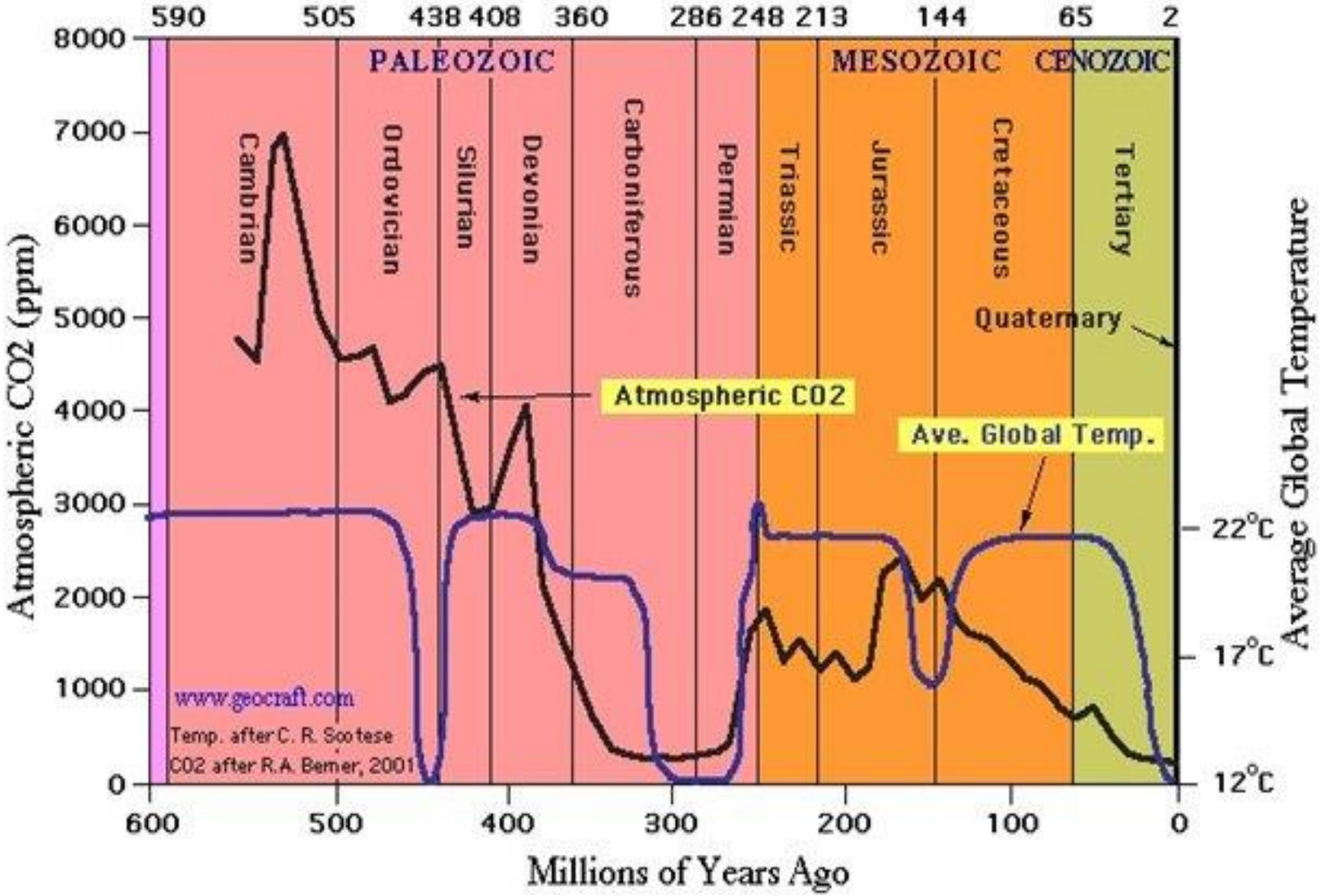



https://upload.wikimedia.org/wikipedia/commons/thumb/0/0b/Citric_acid_cycle_with_aconitate_2.svg/350px-Citric_acid_cycle_with_aconitate_2.svg.png

# Carbon dioxide: planetary temperature regulator

- Liquid water is essential to support living (self-reproducing) organisms.
- Water is liquid between 0 and 100 degrees Celsius. Most organisms thrive in temperatures less than 40 C.
- The CO2 level in the atmosphere intercepts light in certain frequencies. That determines surface temperature
- Most CO2 is now in carbonates or in the oceans

# Long historic relationship between carbon dioxide and temperature




*Source:* *http://www.paulmacrae.com*

# Carbon sequestration (fossil fuels)

- The "carboniferous age" lasted 112 million years, (from 363 million years ago to 251 million years ago.) Earth's climate was warmer and more humid than today, the carbon dioxide level in the atmosphere was much higher, due to volcanoes.
- Dead biomass on land was buried in silt and compressed, "cooked" and turned into coal. Marine biomass ended up as petroleum or methane.
- A small fraction of the carbon that was captured then is now recoverable and usable by humans. But there is enough to "fry us all" if we burn it.

# Skipping over a lot of evolutionary details, from fish to dinosaurs to mammals….

- Several (4?) million years ago there were hominids, living in trees.
- Some of them came down from the trees, walked on two feet, learned to run, lost their hair, and used the other two “feet” for gripping.
- They also learned to plan. For that they needed language.
- Their brains got bigger to accommodate this need. They are us.

# The stone age and pre-history: From the caves to the cities

- Weapons and tools: Arrows and spears, hammers and knives
- Taming fire: cooking, clay pots, metallurgy
- Taming animals (dogs, cats, cattle, horses..)
- Agriculture (seeds, breeding, irrigation)
- Walls for protection (villages, towns, cities)
- Social organization (tribal fights, wars to acquire land)
- Language, symbols, art

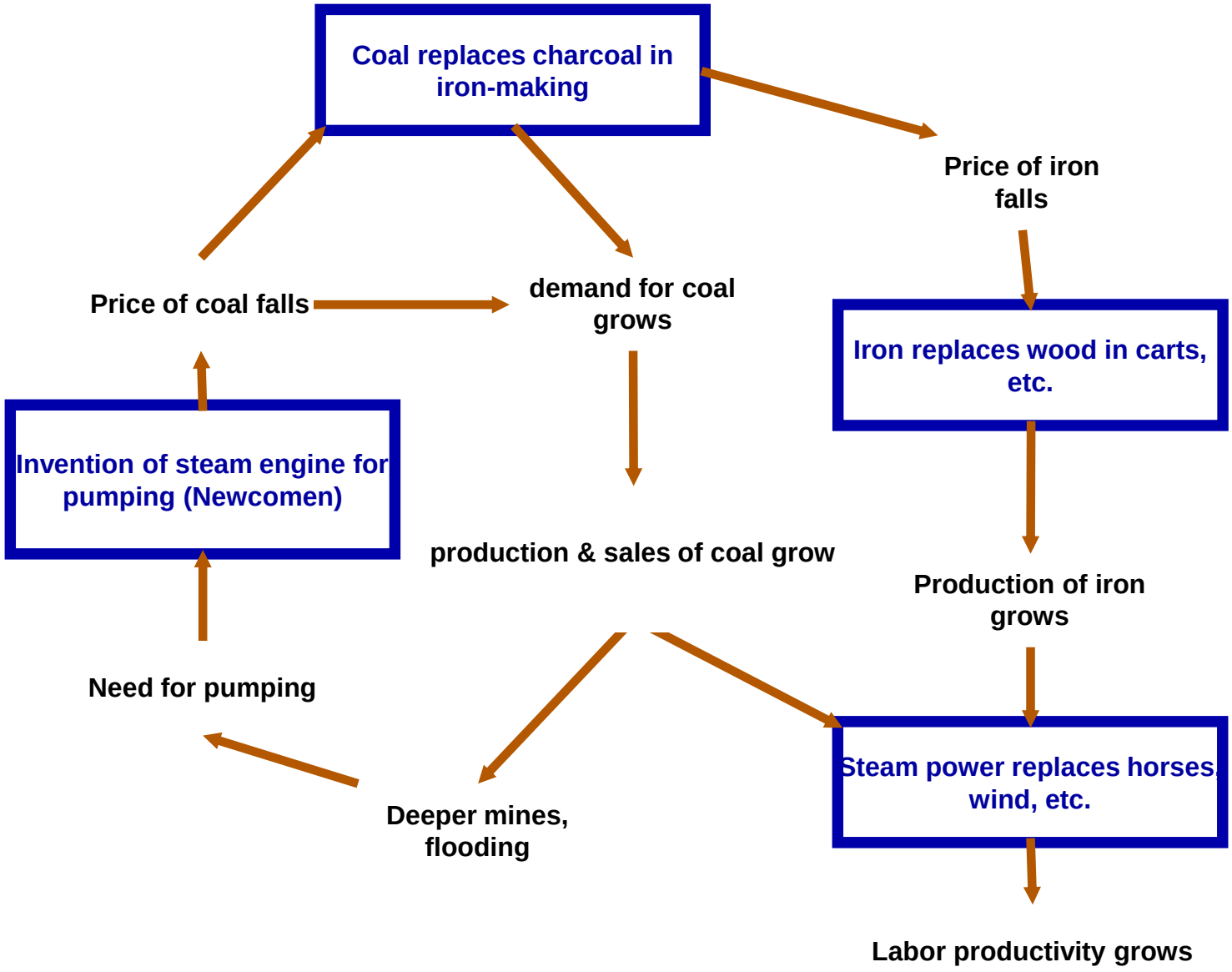
# From clay tablets (8000 BCE) to printed books (1500 CE)

- Metallurgy: the manufacture of weapons and armor, a well as plows and iron pots
- Clothing: from animal skins to leather and woven textiles (wool, linen, silk)
- Mobility: horses, carts and carriages, ships propelled by oars and sails
- Social organization: hierarchies and ranks, classification by occupation (caste)
- Communication: words, symbols, alphabets, numbers, records (clay tablets, skins, paper)
- Money and trade; the rise of capitalism
- The transition from hunting and gathering in the forest to agriculture

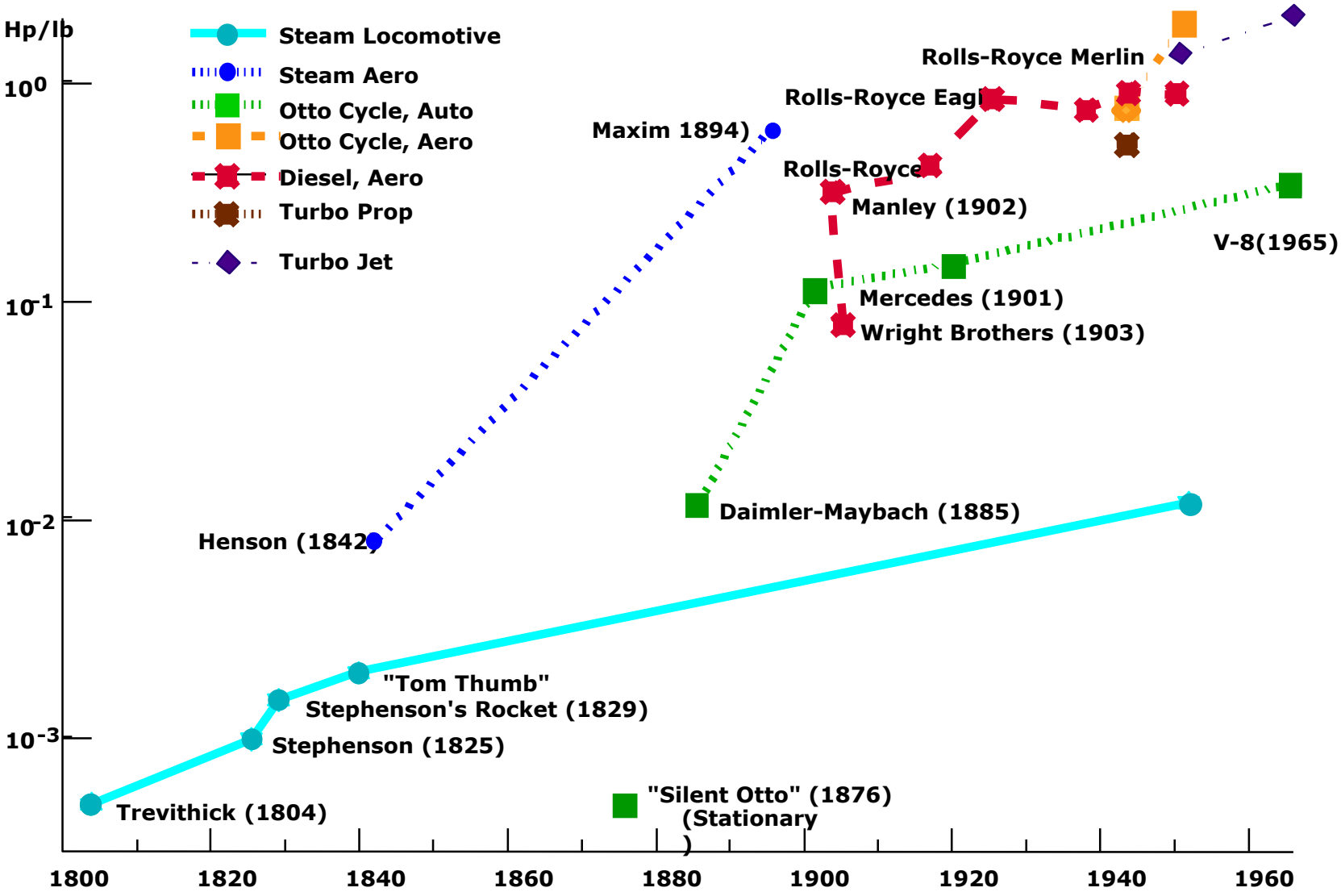
# Since long-distance sea travel..

- Fall of Constantinople (1452) & closure of the "silk road" by Ottoman Turks.
- Portuguese explorers (Vasco da Gama, et al)
- Replication by printing on paper (1450)
- The Reformation and the religious wars
- Deforestation, coking of coal, iron & railroads
- The Industrial Revolution, coal, steam & steel
- Whales, rock oil, the ICE and the automobile
- Electricity, telecommunication, electrification.
- Digital technology, the internet, the cell-phone

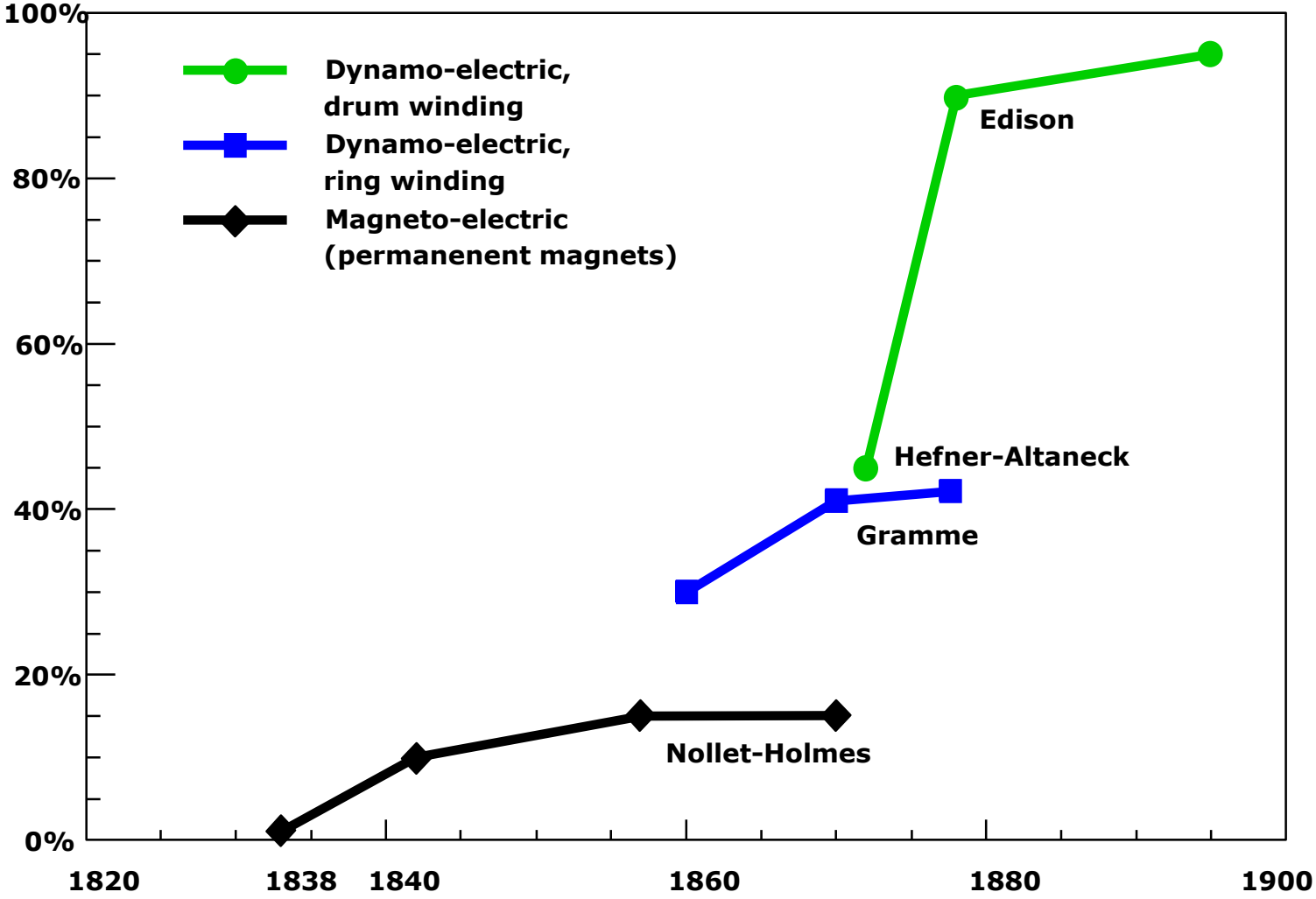
# The first industrial revolution



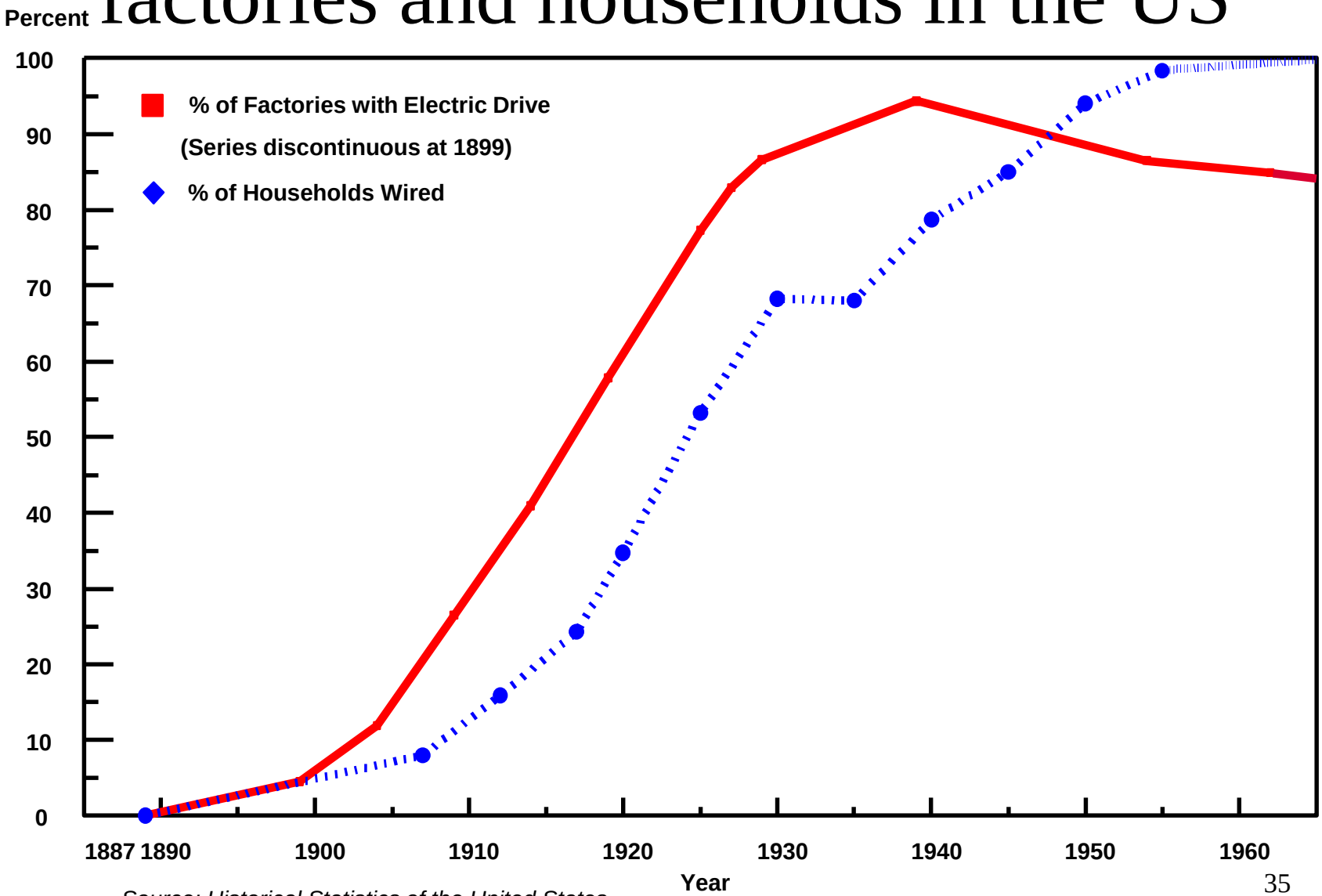
# Progress of internal combustion engines



# 19th century generator efficiency: Electric power output per unit of mechanical power output

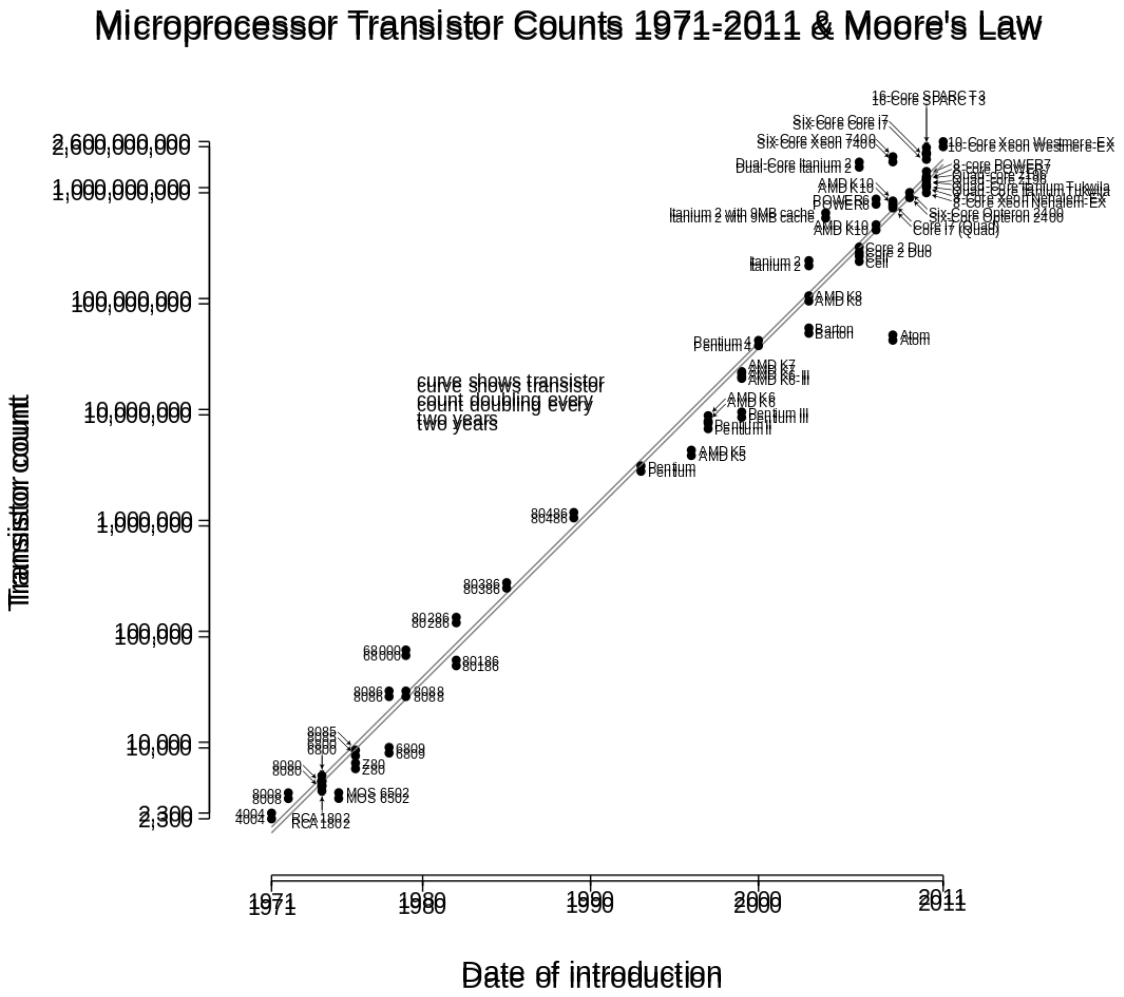


# Rapid growth of electrification of factories and households in the US

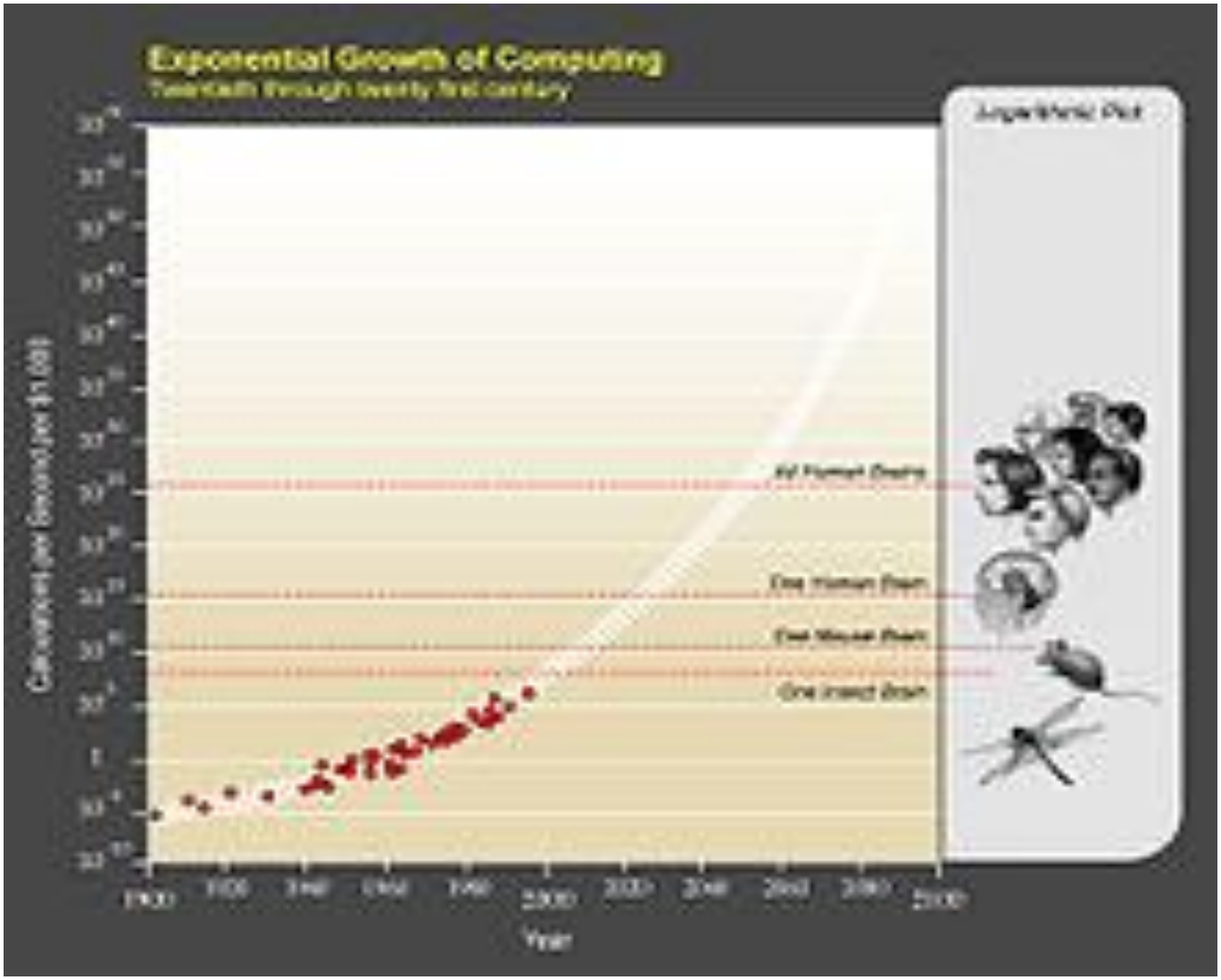



*Source: Historical Statistics of the United States*

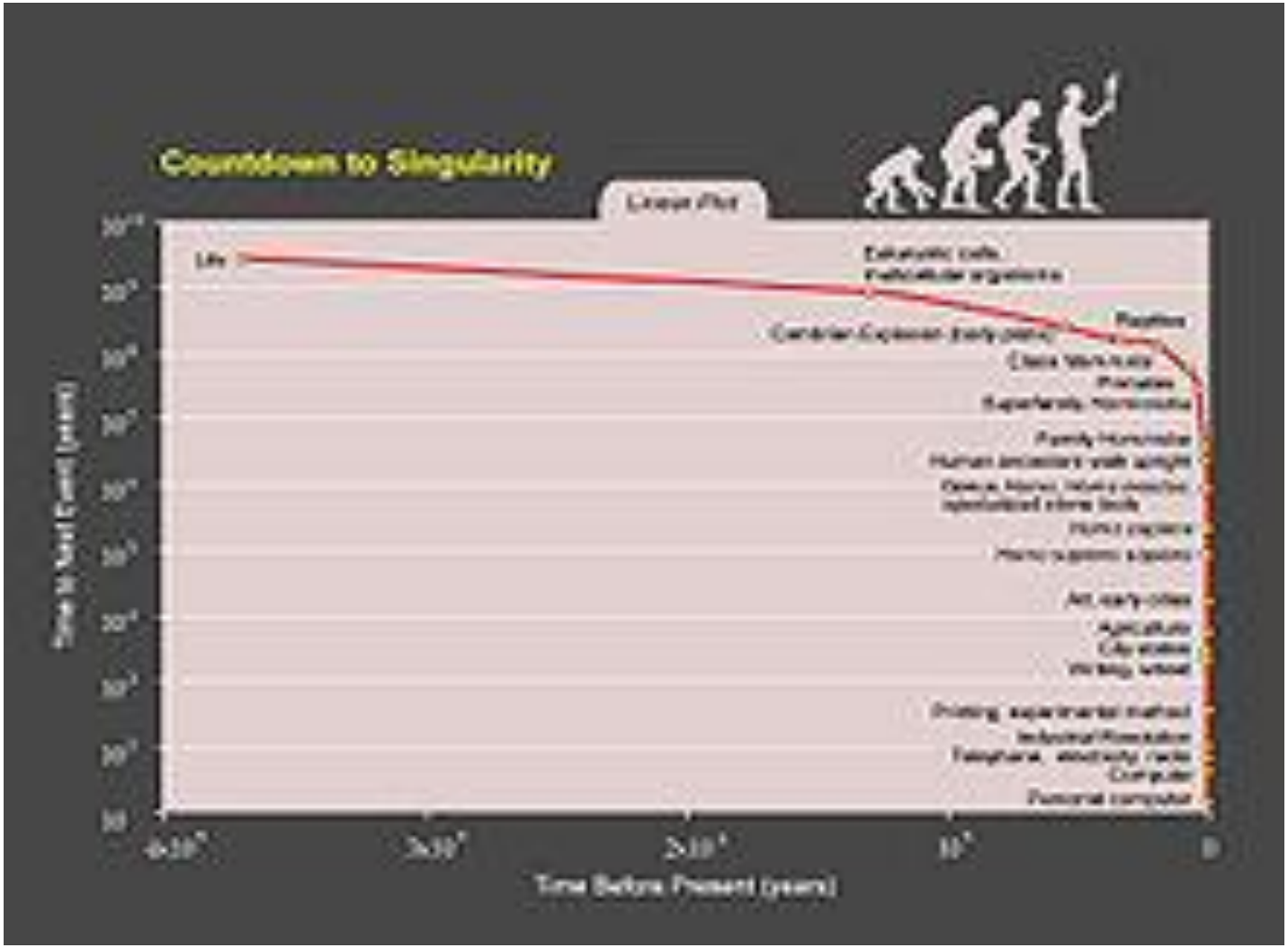
# Moore’s Law: Is there a limit?



# Ray Kurzweil's Singularity



# The count-down to singularity



# Where does it end? Some things to think about.

- Will computers and robots take over?
- Will we learn to live much longer?
- What happens when the oil really runs out? Can renewables replace oil?
- Is nuclear power (uranium, thorium or tritium) the answer?
- What about rare metals? Can we mine the asteroids?

# More things to think about…

- What happens when the fresh water runs out?
- Can the world feed itself?
- Can we prevent climate change?
- Can we end poverty?
- Can we live with extreme inequality?
- Can we live with each other?

# Thanks for your patience…and for your thoughts